STEAM TURBINE

A **steam turbine** is a device that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft. Its modern manifestation was invented by Sir Charles Parsons in 1884.

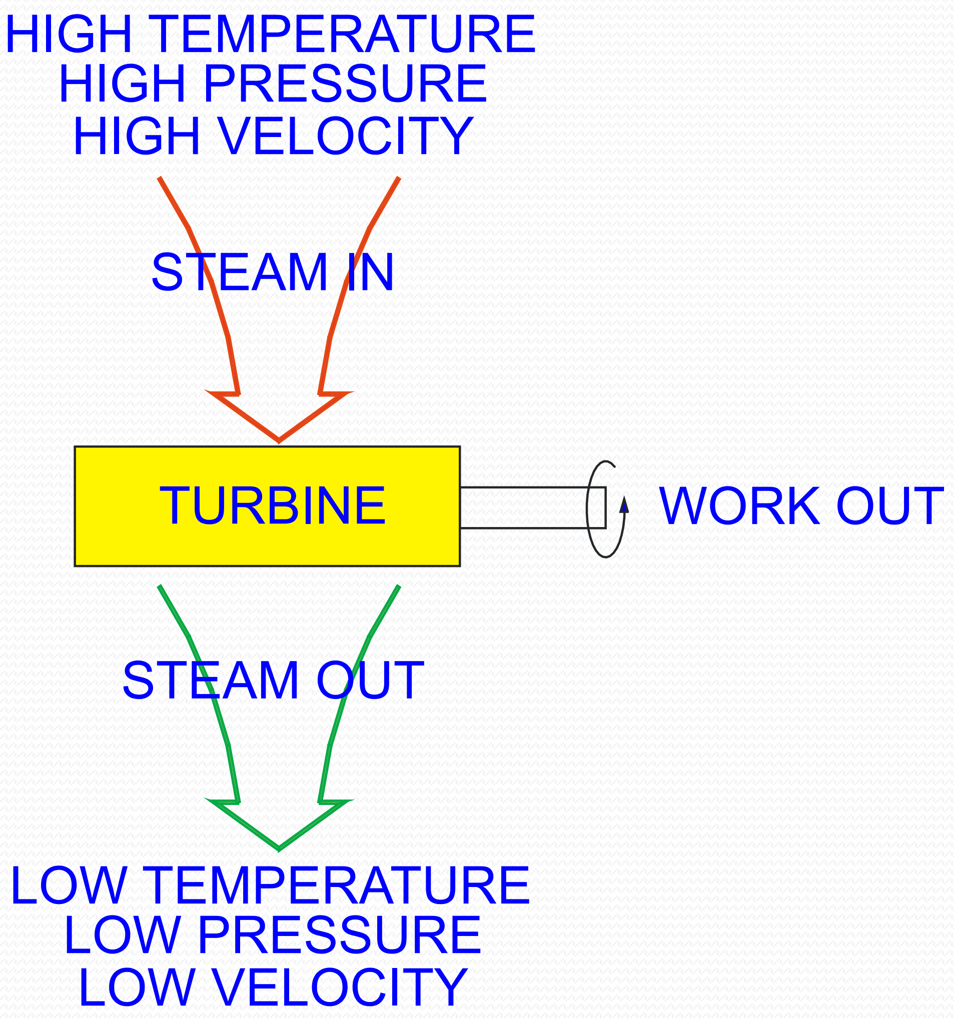
Steam Turbine may also be define as a device which converts heat energy of to the steam to the mechanical energy which finally converted into electrical energy.

Because the turbine generates rotary motion, it is particularly suited to be used to drive an electrical generator – about 90% of all electricity generation in the United States, is by use of steam turbines. The steam turbine is a form of heat engine that derives much of its improvement in thermodynamic efficiency through the use of multiple stages in the expansion of the steam, which results in a closer approach to the ideal reversible process.

The modern steam turbine was invented in 1884 by Sir Charles Parsons, whose first model was connected to a dynamo that generated 7.5 kW (10 hp) of electricity. The Parsons turbine also turned out to be easy to scale up. Parsons had the satisfaction of seeing his invention adopted for all major world power stations, and the size of generators had increased from his first 7.5 kW set up to units of 500MW capacity.

Steam turbines are made in a variety of sizes ranging from small <0.75 kW units used as mechanical drives for pumps, compressors and other shaft driven equipment, to 1,500 MW turbines used to generate electricity. There are several classifications for modern steam turbines.

WORK IN A TURBINE VISUALIZED



Further the steam turbine is based upon Rankine cycle

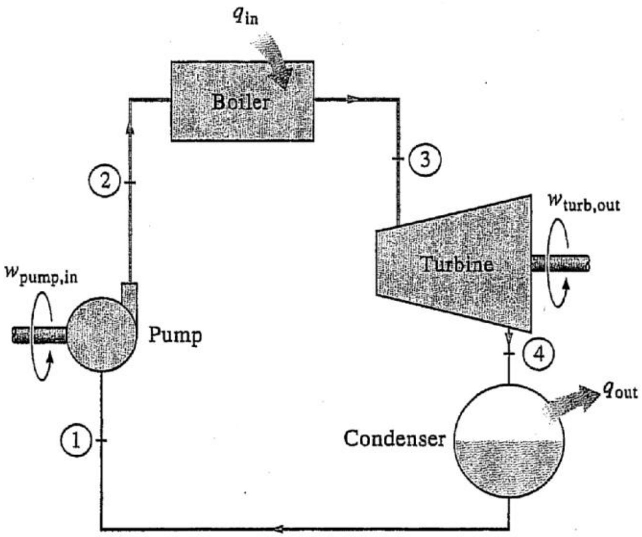
- An ideal Rankine cycle operates between pressures of 30 kPa and 6 MPa. The temperature of the steam at the inlet of the turbine is 550°C. Find the net work for the cycle and the thermal efficiency.
  - $W_{net}=W_{turbine}-W_{pump}$ OR $Q_{in}-Q_{out}$
  - Thermal efficiency $h_{th}=W_{net}/Q_{in}$
  - Net work done is converted into power output of turbine.

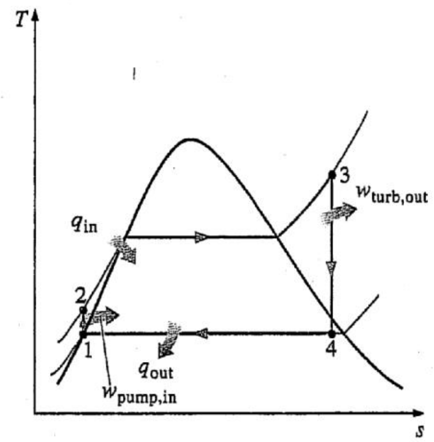
Ideal Rankine Cycle

- This cycle follows the idea of the Carnot cycle but can be practically implemented.

1-2 isentropic pump 2-3 constant pressure heat addition

3-4 isentropic turbine 4-1 constant pressure heat rejection





CLASSIFICATION OF STEAM TURBINE

Classification of steam turbines may be done as following:

1. According to action of steam
   - (a) Impulse turbine
   - (b) Reaction turbine
   - (c) Combination of both

2. According to direction of flow:

(a) Axial flow turbine

(b) Radial flow turbine

3. According to number of stages

(a) Single stage turbine

(b) Multi stage turbine

(4). According to number of cylinders

(a) Single cylinder turbine

(b) Double cylinder turbine

(c) Three cylinder turbine

(5)According to steam pressure at inlet of Turbine:

(a) Low pressure turbine

(b) Medium pressure turbine.

(c) High pressure turbine

(d) Super critical pressure turbine.

(6)According to method of governing:

(a) Throttle governing turbine.

(b) Nozzle governing turbine.

(c) By pass governing turbine.

(7) According to usage in industry:

(a) Stationary turbine with constant speed.

(b) Stationary turbine with variable speed.

(c) Non stationary turbines.

Description of common types of Turbines.

The common types of steam turbine are

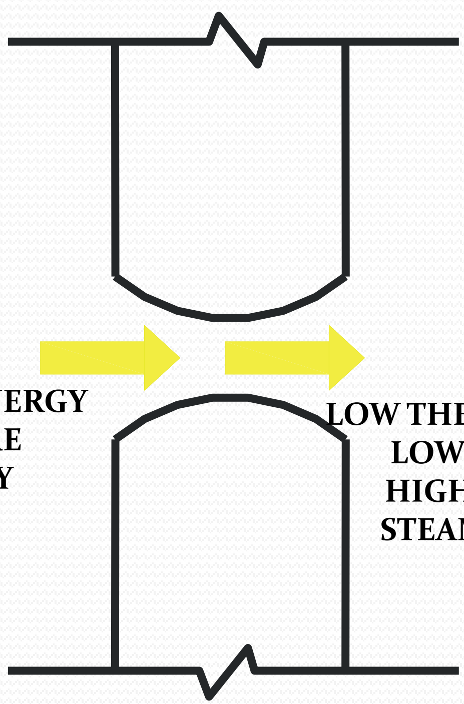
1. Impulse Turbine.
2. Reaction Turbine.

The main difference between these two turbines lies in the way of expanding the steam while it moves through them.

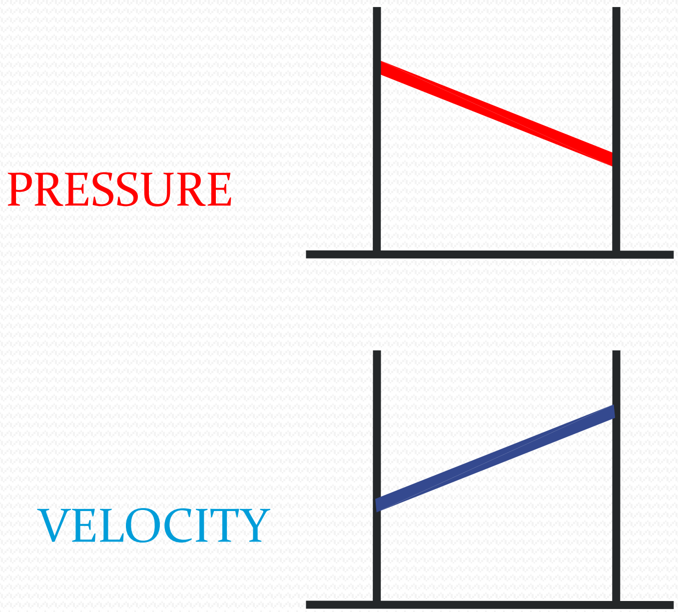
In the **impulse turbine**, the steam expands in the nozzles and it's pressure does not alter as it moves over the blades. In the reaction turbine the steam expanded continuously as it passes over the blades and thus there is gradually fall in the pressure during expansion below the atmospheric pressure.

PRESSURE-VELOCITY DIAGRAM FOR A TURBINE NOZZLE

<u>ENTRANCE</u>
HIGH THERMAL ENERGY
HIGH PRESSURE
LOW VELOCITY
STEAM INLET



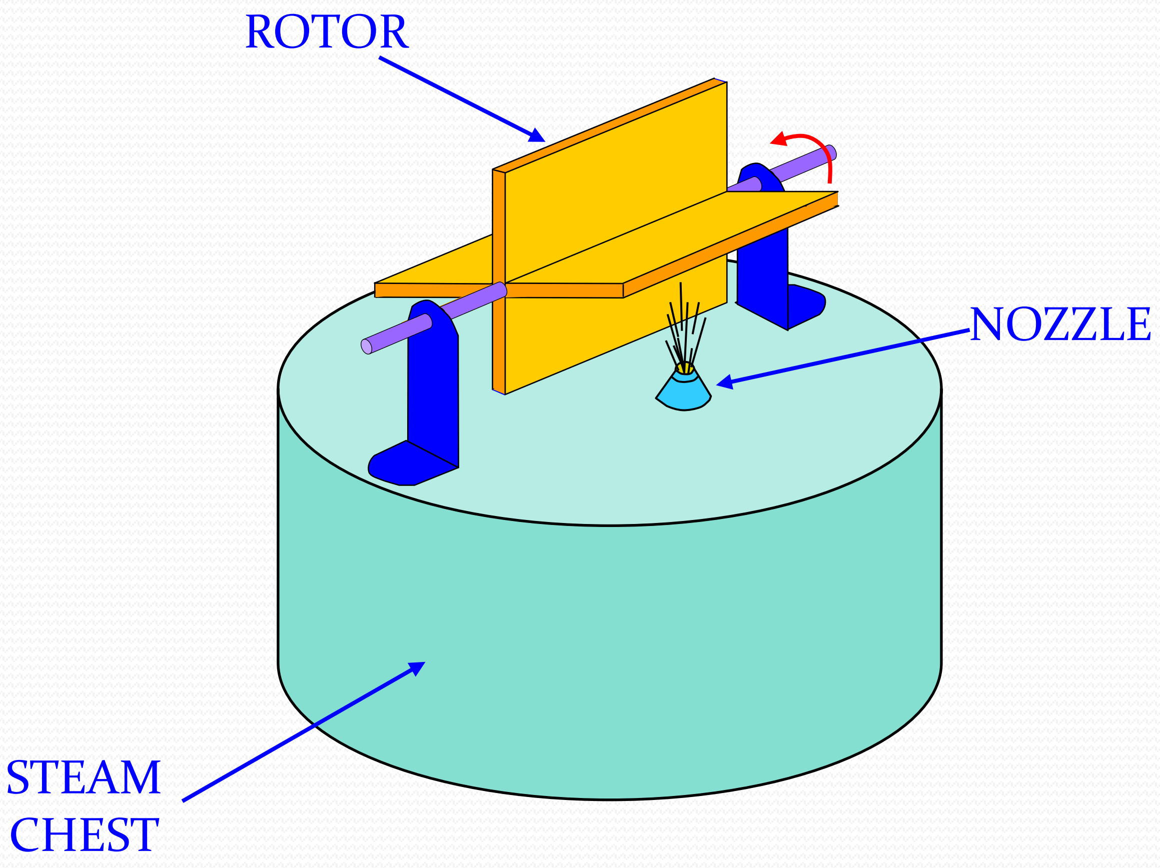
<u>EXIT</u>
LOW THERMAL ENERGY
LOW PRESSURE
HIGH VELOCITY
STEAM EXHAUST

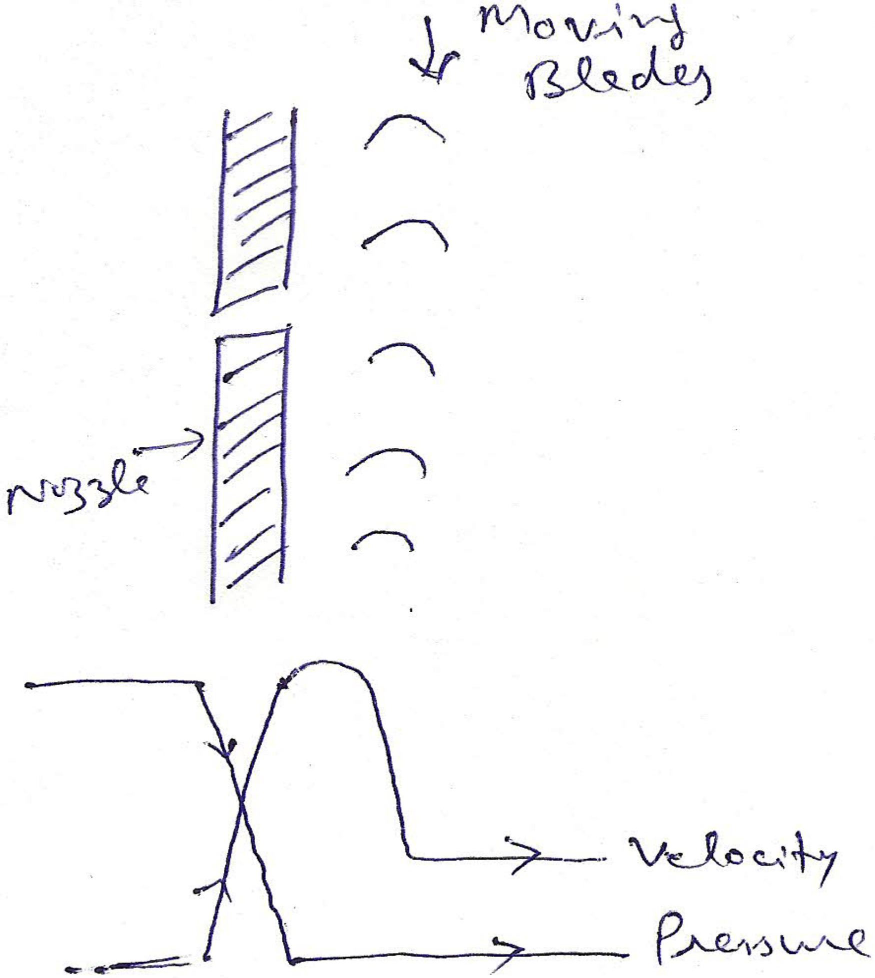


Simple impulse Turbine.

It the impulse turbine, the steam expanded within the nozzle and there is no any change in the steam pressure as it passes over the blades

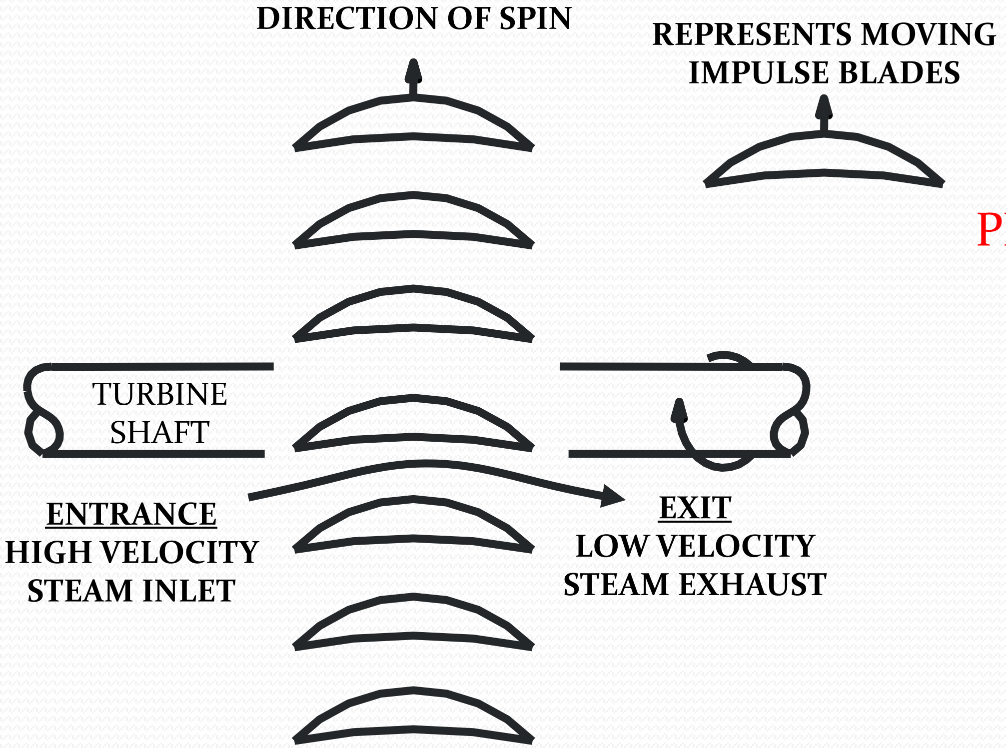
IMPULSE TURBINE PRINCIPLE

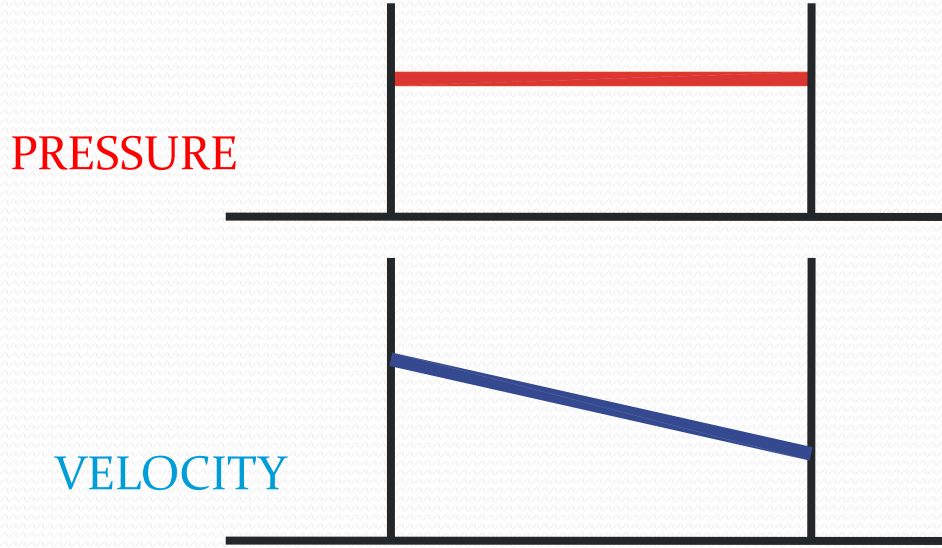




Impulse Turbine

PRESSURE-VELOCITY DIAGRAM FOR A MOVING IMPULSE BLADE





Reaction Turbine

In this type of turbine, there is a gradual pressure drop and takes place continuously over the fixed and moving blades. The rotation of the shaft and drum, which carrying the blades is the result of both impulse and reactive force in the steam. The reaction turbine consist of a row of stationary blades and the following row of moving blades

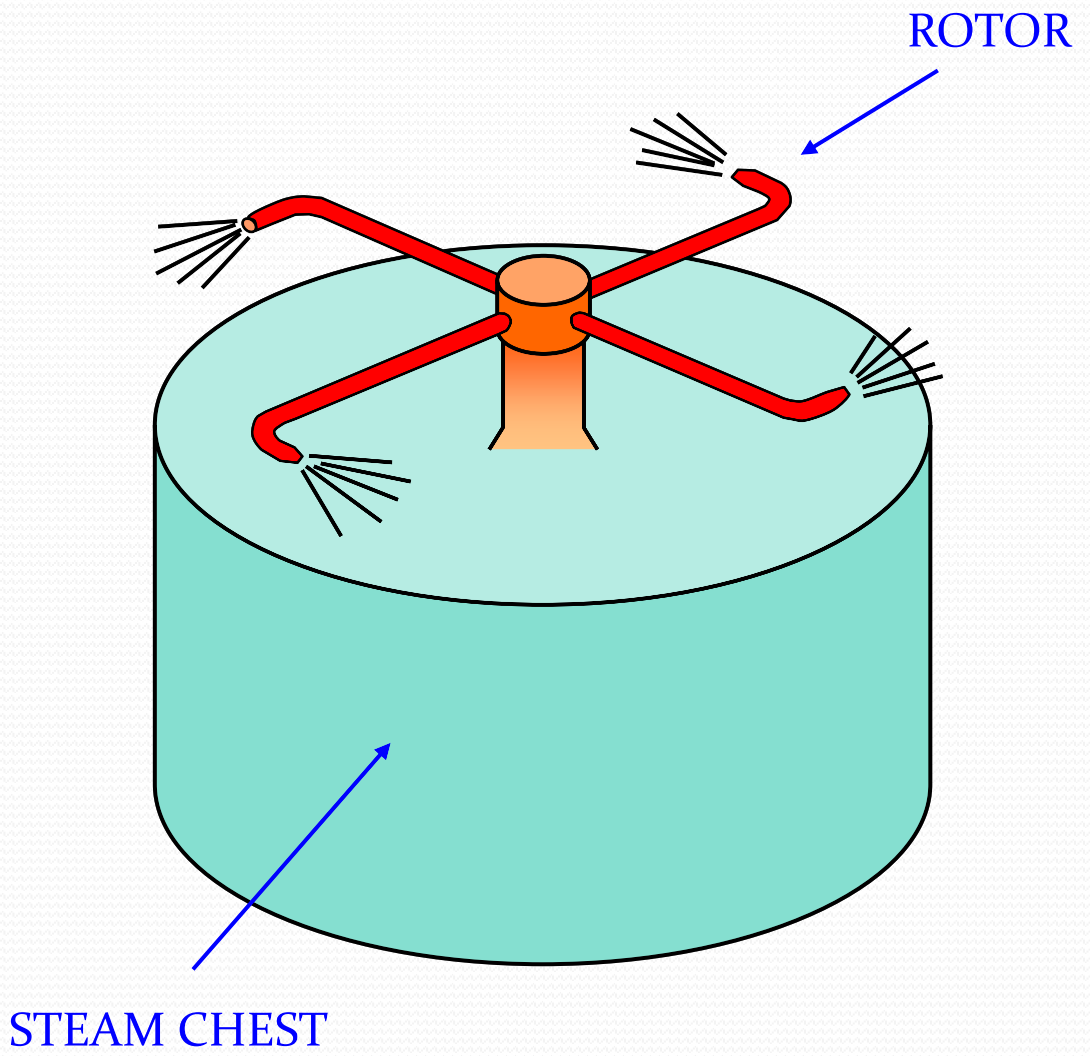
The fixed blades act as a nozzle which are attached inside the cylinder and the moving blades are fixed with the rotor as shown in figure

When the steam expands over the blades there is gradual increase in volume and decrease in pressure. But the velocity decrease in the moving blades and increases in fixed blades with change of direction.

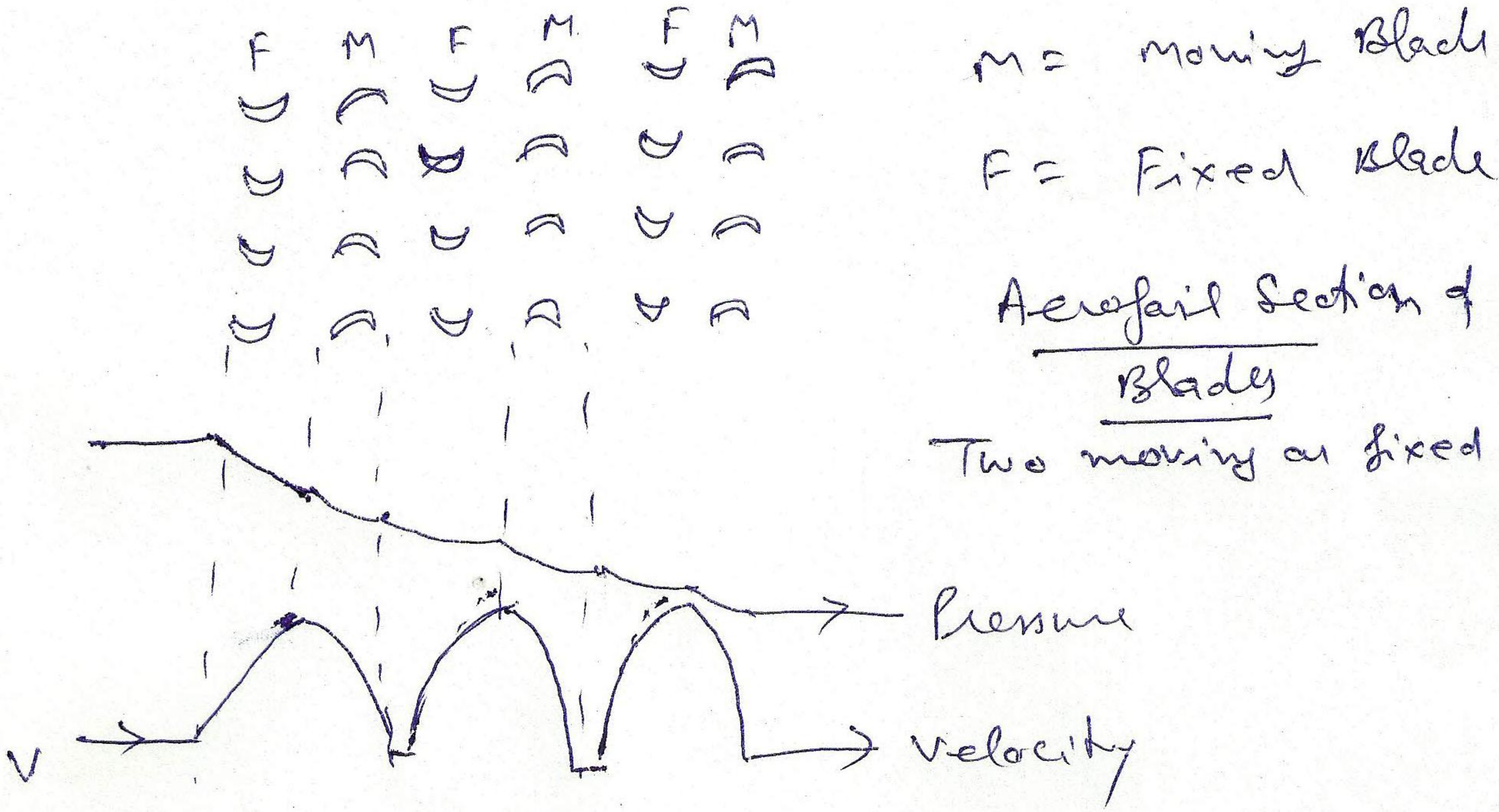
Because of the pressure drops in each stage, the number of stages required in a reaction turbine is much greater than in a impulse turbine of same capacity.

It also concluded that as the volume of steam increases at lower pressures therefore the diameter of the turbine must increase after each group of blade rings.

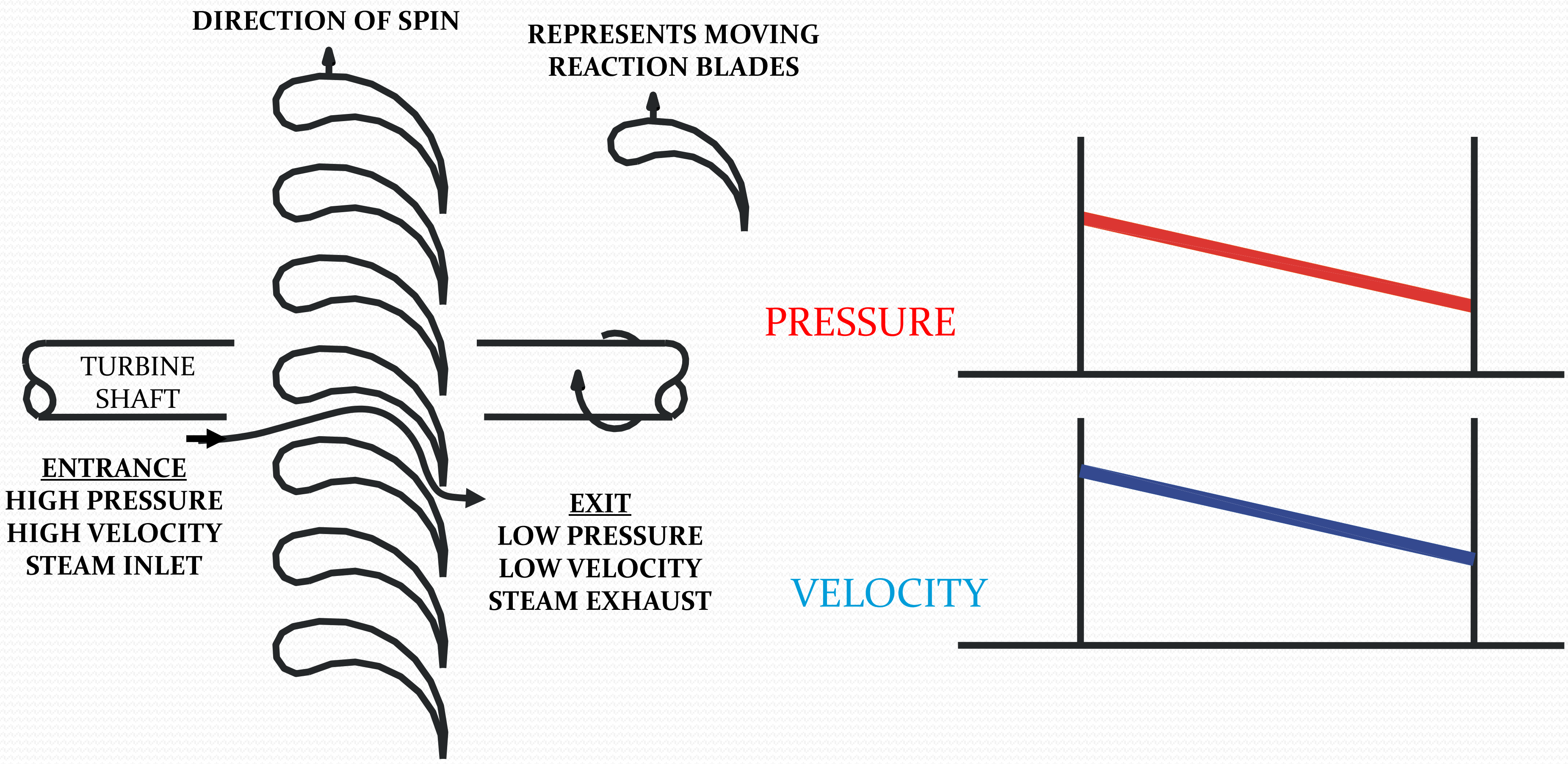
REACTION TURBINE PRINCIPLE

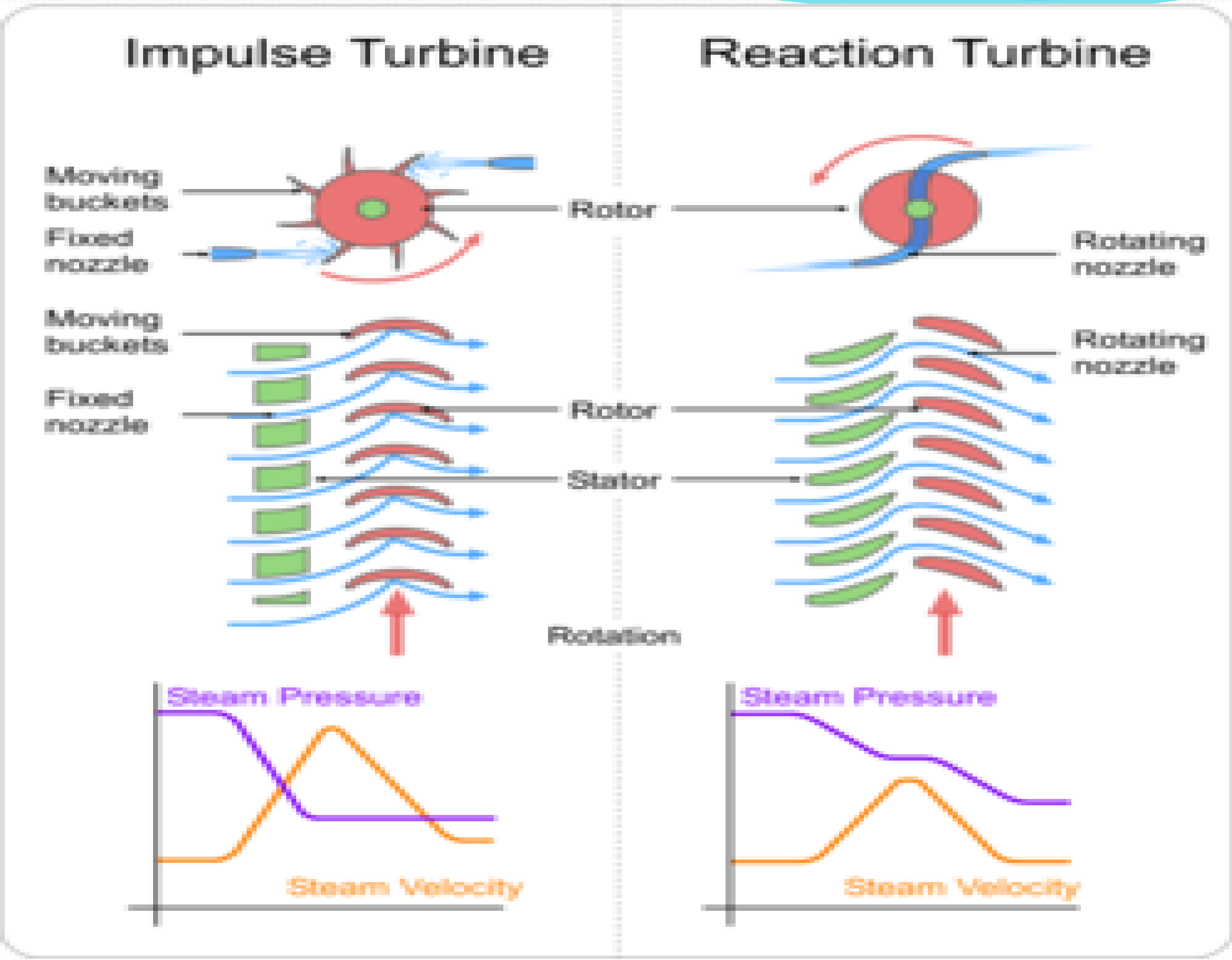


Reaction Turbine



PRESSURE-VELOCITY DIAGRAM FOR A MOVING REACTION BLADE




Impulse Turbine
Reaction Turbine
Moving buckets
Fixed nozzle
Rotor
Rotating nozzle
Moving buckets
Fixed nozzle
Rotating nozzle
Rotor
Stator
Rotation
Steam Pressure
Steam Velocity
Steam Pressure
Steam Velocity

.**Compounding in Steam Turbine.**

The compounding is the way of reducing the wheel or rotor speed of the turbine to optimum value. It may be defined as the process of arranging the expansion of steam or the utilization of kinetic energy or both in several rings.

There are several methods of reducing the speed of rotor to lower value. All these methods utilize a multiple system of rotors in series keyed on a common shaft, and the seam pressure or jet velocity is absorbed in stages as the steam flower over the blades.

Different methods of compounding are:

1. **Velocity Compounding**
2. **Pressure Compounding**
3. **Pressure Velocity Compounding.**

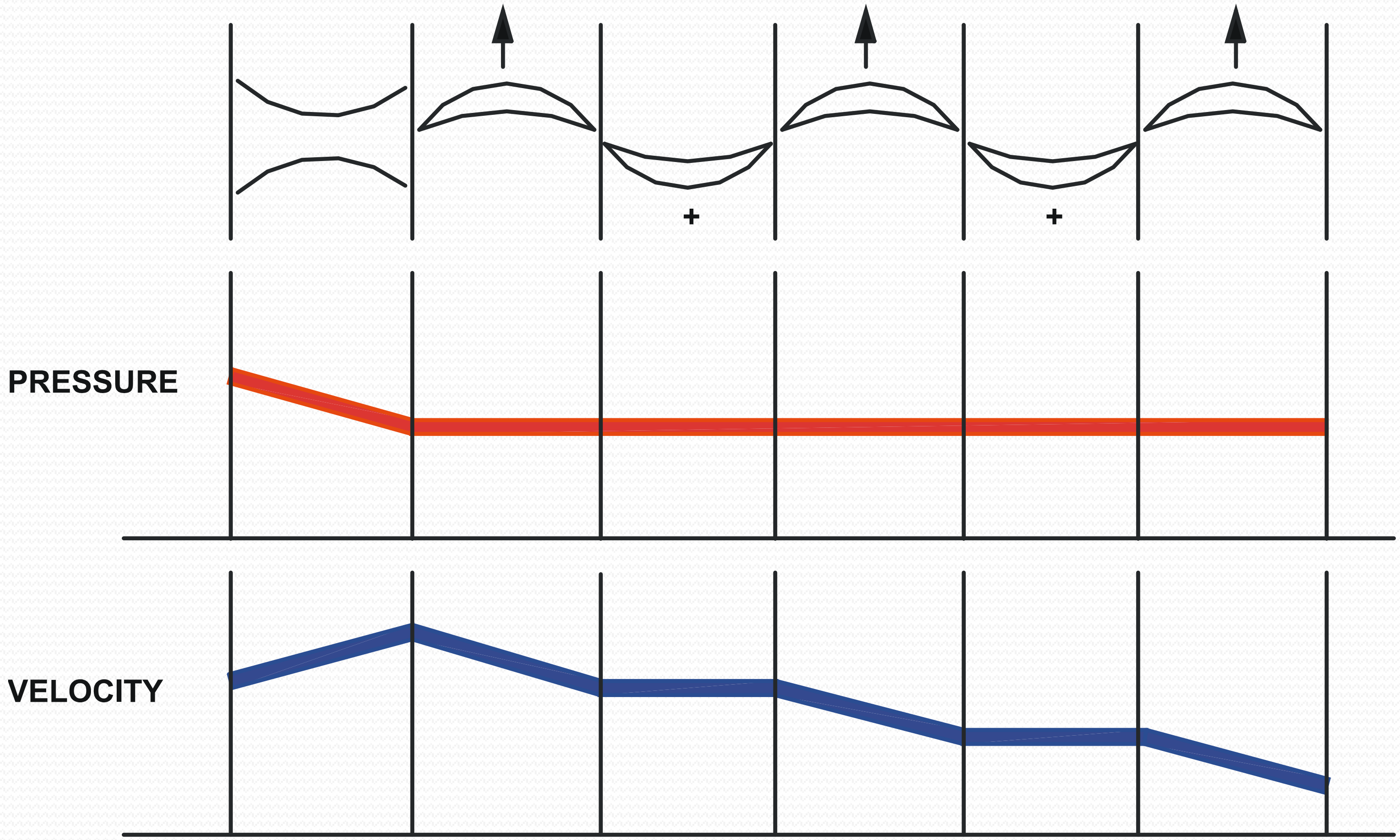
These are explained in detail as given below:

Velocity Compounding:

There are number of moving blades separated by rings of fixed blades as shown in the figure. All the moving blades are keyed on a common shaft. When the steam passed through the nozzles where it is expanded to condenser pressure. It's Velocity becomes very high. This high velocity steam then passes through a series of moving and fixed blades

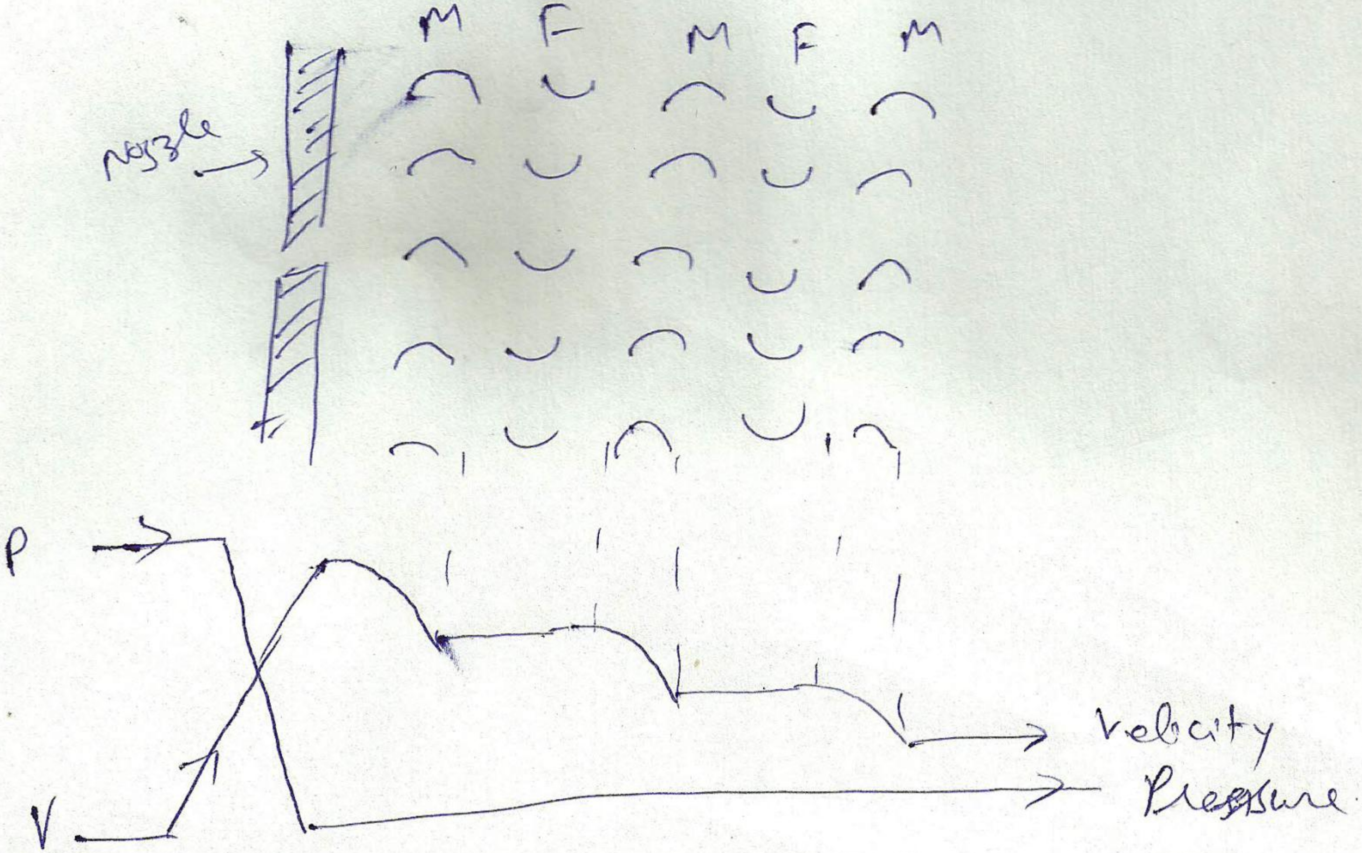
When the steam passes over the moving blades it's velocity decreases. The function of the fixed blades is to re-direct the steam flow without altering it's velocity to the following next row moving blades where a work is done on them and steam leaves the turbine with allow velocity as shown in diagram.

VELOCITY COMPOUNDED TURBINE



VISUALIZATION OF A VELOCITY COMPOUNDED TURBINE

Velocity Compounding



Pressure Compounding:

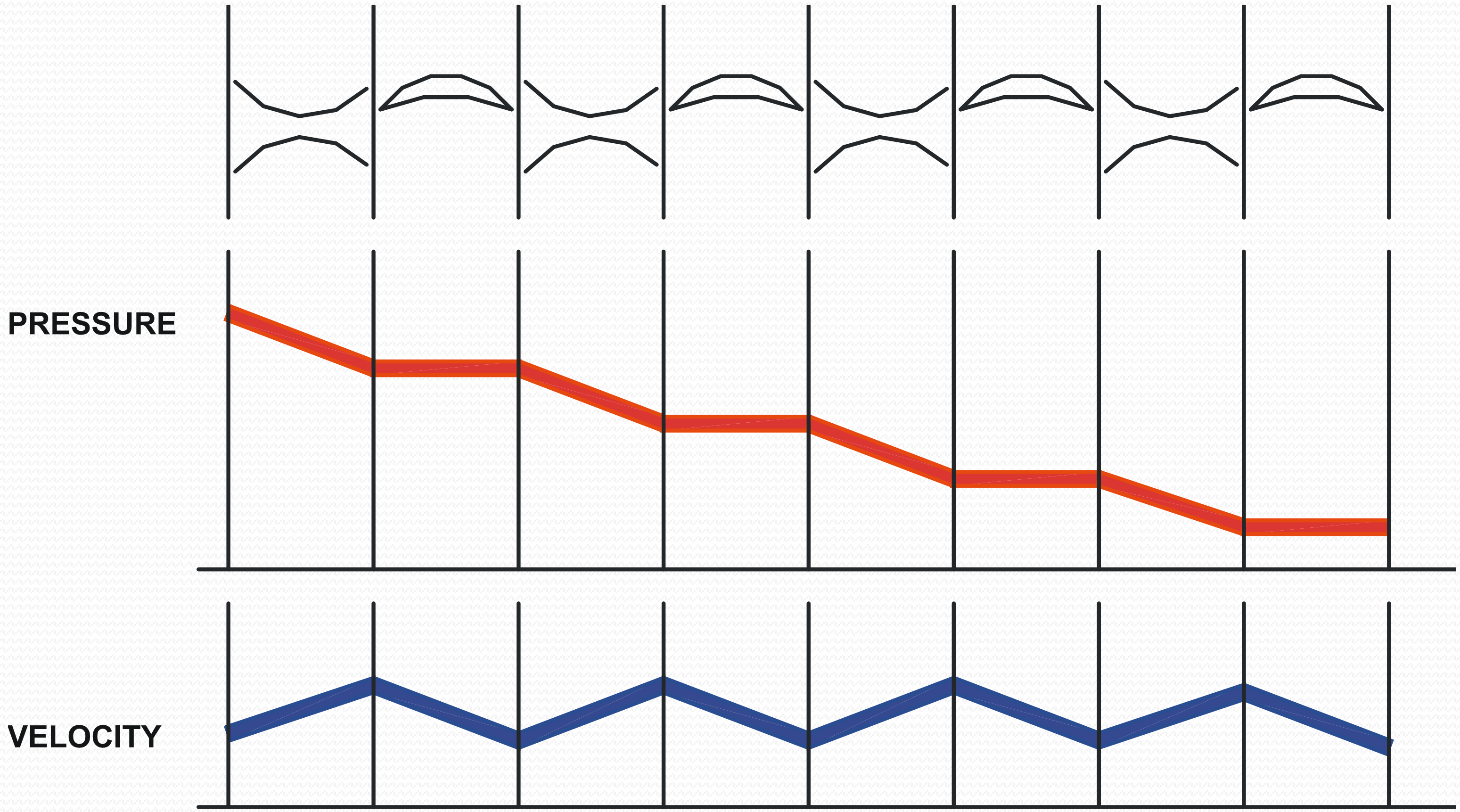
These are the rings of moving blades which are keyed on a same shaft in series, are separated by the rings of fixed nozzles.

The steam at boiler pressure enters the first set of nozzles and expanded partially. The kinetic energy of the steam thus obtained is absorbed by moving blades.

The steam is then expanded partially in second set of nozzles where it's pressure again falls and the velocity increase the kinetic energy so obtained is absorbed by second ring of moving blades.

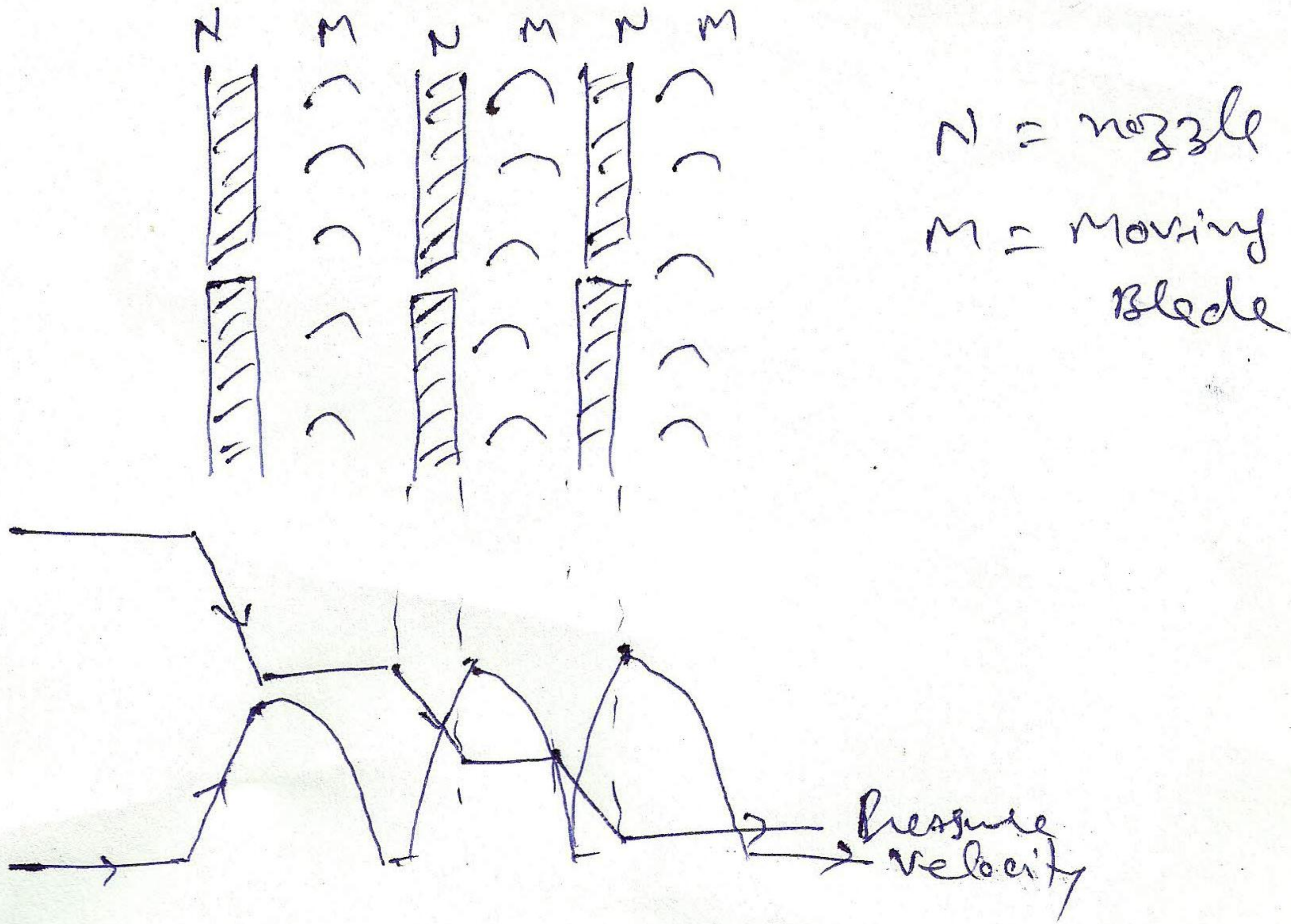
This process repeats again and again and at last, steam leaves the turbine at low velocity and pressure. During entire process, the pressure decrease continuously but the velocity fluctuate as shown in diagram.

PRESSURE COMPOUNDED TURBINE



VISUALIZATION OF A PRESSURE COMPOUNDED TURBINE

Pressure Compounding

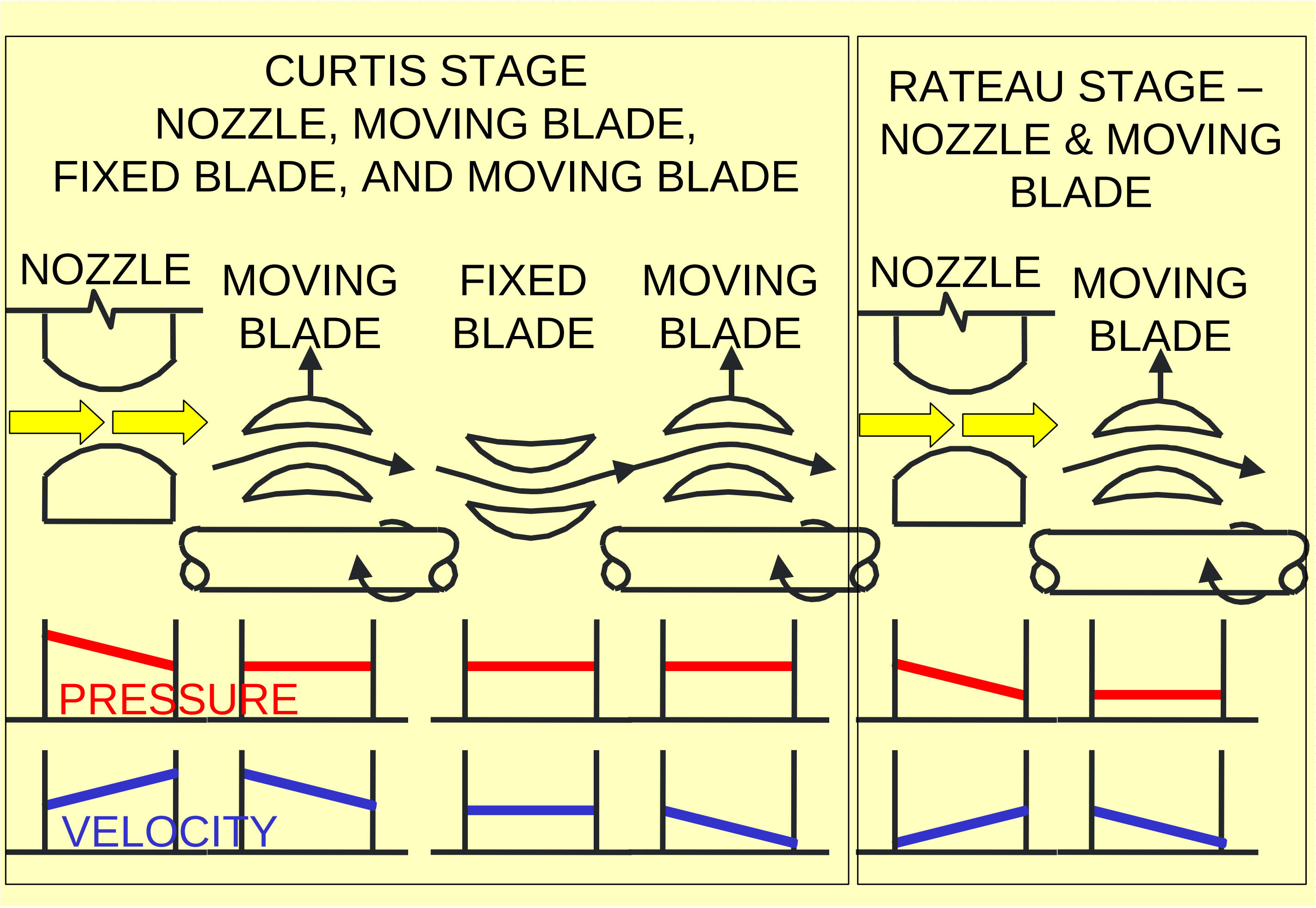


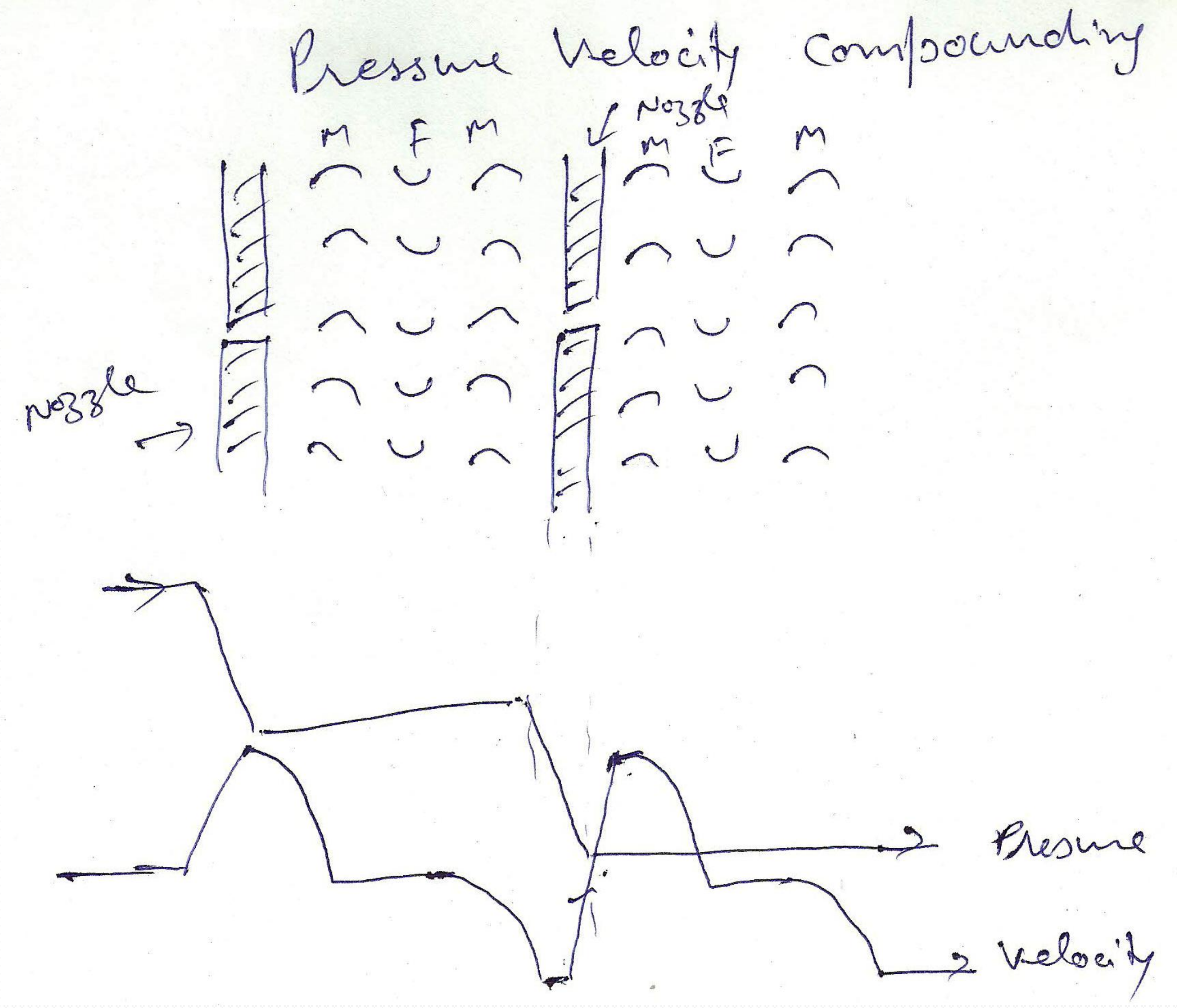
Pressure velocity compounding

This method of compounding is the combination of two previously discussed methods. The total drop in steam pressure is divided into stages and the velocity obtained in each stage is also compounded. The rings of nozzles are fixed at the beginning of each stage and pressure remains constant during each stage as shown in figure.

The turbine employing this method of compounding may be said to combine many of the advantages of both pressure and velocity staging By allowing a bigger pressure drop in each stage, less number stages are necessary and hence a shorter turbine will be obtained for a given pressure drop.

PRESSURE-VELOCITY COMPOUNDED IMPULSE TURBINE




Pressure Velocity compounding
Nozzle
M F M
M F M
Nozzle
Pressure
Velocity

Steam supply and exhaust conditions

These types include condensing, non-condensing, reheat, extraction and induction.

Condensing turbines are most commonly found in electrical **power plants**. These turbines exhaust steam in a partially condensed state, typically of a quality near 90%, at a pressure well below atmospheric to a condenser.

Non-condensing or back pressure turbines are most widely used for process steam applications. The exhaust pressure is controlled by a regulating valve to suit the needs of the process steam pressure. These are commonly found at refineries, heating units, pulp and paper plants, and desalination facilities where large amounts of low pressure process steam are available.

Reheat turbines are also used almost exclusively in electrical power plants. In a reheat turbine, steam flow exits from a high pressure section of the turbine and is returned to the boiler where additional superheat is added. The steam then goes back into an intermediate pressure section of the turbine and continues its expansion.

Extracting type turbines are common in all applications. In an extracting type turbine, steam is released from various stages of the turbine, and used for industrial process needs or sent to boiler feedwater heaters to improve overall cycle efficiency. Extraction flows may be controlled with a valve, or left uncontrolled.

Induction turbines introduce low pressure steam at an intermediate stage to produce additional power.

Casing or shaft arrangements

These arrangements include single casing, tandem compound and cross compound turbines. Single casing units are the most basic style where a single casing and shaft are coupled to a generator. Tandem compound are used where two or more casings are directly coupled together to drive a single generator.

A cross compound turbine arrangement features two or more shafts not in line driving two or more generators that often operate at different speeds. A cross compound turbine is typically used for many large applications.

Two-flow rotors

A two-flow turbine rotor. The steam enters in the middle of the shaft, and exits at each end, balancing the axial force.

The moving steam imparts both a tangential and axial thrust on the turbine shaft, but the axial thrust in a simple turbine is unopposed. To maintain the correct rotor position and balancing, this force must be counteracted by an opposing force.

Either thrust bearings can be used for the shaft bearings, or the rotor can be designed so that the steam enters in the middle of the shaft and exits at both ends. The blades in each half face opposite ways, so that the axial forces negate each other but the tangential forces act together. This design of rotor is called **two-flow** or **double-exhaust**.

Principle of operation and design

An ideal steam turbine is considered to be an isentropic process, or constant entropy process, in which the entropy of the steam entering the turbine is equal to the entropy of the steam leaving the turbine

No steam turbine is truly isentropic, however, with typical isentropic efficiencies ranging from 20–90% based on the application of the turbine.

The interior of a turbine comprises several sets of blades, or *buckets* as they are more commonly referred to. One set of stationary blades is connected to the casing and one set of rotating blades is connected to the shaft.

The sets intermesh with certain minimum clearances, with the size and configuration of sets varying to efficiently exploit the expansion of steam at each stage.

Turbine efficiency

Schematic diagram outlining the difference between an impulse and a 50% reaction turbine

To maximize turbine efficiency the steam is expanded, doing work, in a number of stages. These stages are characterized by how the energy is extracted from them and are known as either impulse or reaction turbines.

Most steam turbines use a mixture of the reaction and impulse designs: each stage behaves as either one or the other, but the overall turbine uses both. Typically, higher pressure sections are impulse type and lower pressure stages are reaction type.

Impulse turbines

An impulse turbine has fixed nozzles that orient the steam flow into high speed jets. These jets contain significant kinetic energy, which is converted into shaft rotation by the bucket-like shaped rotor blades, as the steam jet changes direction.

A pressure drop occurs across only the stationary blades, with a net increase in steam velocity across the stage. As the steam flows through the nozzle its pressure falls from inlet pressure to the exit pressure (atmospheric pressure, or more usually, the condenser vacuum). Due to this high ratio of expansion of steam, the steam leaves the nozzle with a very high velocity.

The steam leaving the moving blades has a large portion of the maximum velocity of the steam when leaving the nozzle. The loss of energy due to this higher exit velocity is commonly called the carry over velocity or leaving loss.

Reaction turbines

In the reaction turbine, the rotor blades themselves are arranged to form convergent nozzles. This type of turbine makes use of the reaction force produced as the steam accelerates through the nozzles formed by the rotor.

Steam is directed onto the rotor by the fixed vanes of the stator. It leaves the stator as a jet that fills the entire circumference of the rotor. The steam then changes direction and increases its speed relative to the speed of the blades.

A pressure drop occurs across both the stator and the rotor, with steam accelerating through the stator and decelerating through the rotor, with no net change in steam velocity across the stage but with a decrease in both pressure and temperature, reflecting the work performed in the driving of the rotor.

Operation and maintenance

When warming up a steam turbine for use, the main steam stop valves (after the boiler) have a bypass line to allow superheated steam to slowly bypass the valve and proceed to heat up the lines in the system along with the steam turbine. Also, a turning gear is engaged when there is no steam to the turbine to slowly rotate the turbine to ensure even heating to prevent uneven expansion.

After first rotating the turbine by the turning gear, allowing time for the rotor to assume a straight plane (no bowing), then the turning gear is disengaged and steam is admitted to the turbine, first to the astern blades then to the ahead blades slowly rotating the turbine at 10–15 RPM (0.17–0.25 Hz) to slowly warm the turbine.

Any imbalance of the rotor can lead to vibration, which in extreme cases can lead to a blade breaking away from the rotor at high velocity and being ejected directly through the casing. To minimize risk it is essential that the turbine be very well balanced and turned with dry steam - that is, superheated steam with a minimal liquid water content

. If water gets into the steam and is blasted onto the blades (moisture carry over), rapid impingement and erosion of the blades can occur leading to imbalance and catastrophic failure. Also, water entering the blades will result in the destruction of the thrust bearing for the turbine shaft.

To prevent this, along with controls and baffles in the boilers to ensure high quality steam, condensate drains are installed in the steam piping leading to the turbine. Modern designs are sufficiently refined that problems with turbines are rare and maintenance requirements are relatively small.

The steam turbine operates on basic principles of thermodynamics using the part of the Rankine cycle. Superheated vapor (or dry saturated vapor, depending on application) enters the turbine, after it having exited the boiler, at high temperature and high pressure. The high heat/pressure steam is converted into kinetic energy using a nozzle. Once the steam has exited the nozzle it is moving at high velocity and is sent to the blades of the turbine.

A force is created on the blades due to the pressure of the vapor on the blades causing them to move. A generator or other such device can be placed on the shaft, and the energy that was in the vapor can now be stored and used.

The gas exits the turbine as a saturated vapor (or liquid-vapor mix depending on application) at a lower temperature and pressure than it entered with and is sent to the condenser to be cooled

Isentropic turbine efficiency

To measure how well a turbine is performing we can look at its isentropic efficiency. This compares the actual performance of the turbine with the performance that would be achieved by an ideal, isentropic, turbine. When calculating this efficiency, heat lost to the surroundings is assumed to be zero.

The starting pressure and temperature is the same for both the actual and the ideal turbines, but at turbine exit the energy content ('specific enthalpy') for the actual turbine is greater than that for the ideal turbine because of irreversibility in the actual turbine.

The isentropic efficiency is found by dividing the actual work by the ideal work.

where

- ***h*** $_1$ is the specific enthalpy at state one
- ***h*** $_2$ is the specific enthalpy at state two for the actual turbine
- ***h*** $_{2s}$ is the specific enthalpy at state two for the isentropic turbine

$$\frac{\dot{W}}{\dot{m}} = h_1 - h_2$$